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Non-radial Pulsations in the Open Cluster NGC 3766

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Abstract. Non-radial pulsations (NRPs) are a proposed mechanism for the formation of decretion disks around Be stars and are important tools to study the internal structure of stars. NGC 3766 has an unusually large fraction of transient Be stars, so it is an excellent location to study the formation mechanism of Be star disks. High resolution spectroscopy can reveal line profile variations from NRPs, allowing measurements of both the degree, l, and azimuthal order, m. However, spectroscopic studies require large amounts of time with large telescopes to achieve the necessary high S/N and time domain coverage. On the other hand, multi-color photometry can be performed more easily with small telescopes to measure l only. Here, we present representative light curves of Be stars and non-emitting B stars in NGC 3766 from the CTIO 0.9m telescope in an effort to study NRPs in this cluster.

Keywords. open clusters and associations: individual (NGC 3766) — stars: emission-line, Be — stars: oscillations (including pulsations)

1. Introduction

Be stars are a class of non-supergiant B-type stars with Balmer and other line emission features due to an equatorial decretion disk. The disk is likely the result of a combination of the star's rapid rotation (near the critical limit) and non-radial pulsations (NRPs; Porter & Rivinius 2003).

NRPs are spherical harmonic waves traversing the surface of a star. These pulsations can be found in multiple frequencies on the surface simultaneously (Rivinius, Baade, & Štefl 2003). There are two primary classes of NRP modes: g- and p-modes. g-modes are described by a low frequency pulsation that has gravity as its restoring force. The dominant oscillation in this mode is transverse across the surface. p-modes are dominated by high frequency, radial oscillations with a pressure restoring force (De Ridder 2001). These modes in main-sequence, pulsating B stars are driven by the κ mechanism (Gutiérrez-Soto et al. 2007).

Temperature and flux gradients are established between the dimmer, cooler material on the peaks of the pulsations and the brighter, warmer material in the troughs. The flux variations over the stellar surface are then observed as either ripples within photospheric absorption line profiles or as periodic variations in magnitude. A large, high-resolution spectroscopic study would reveal both the degree, l, and the azimuthal order, m, but such studies are challenging due to the need for large amounts of time on a large telescope. Photometry, which is easily performed with data gathered by small telescopes, only measures l (Rivinius, Baade, & Štefl 2003).

McSwain et al. (2008) previously showed that NGC 3766, an open cluster in Centaurus,

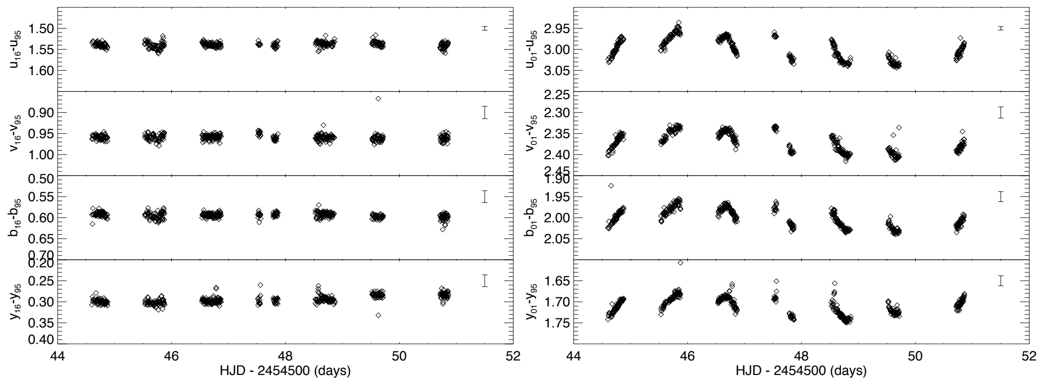

Figure 1. On the left, Strömgren *uvby* differential magnitudes are plotted for two check stars, Nos. 16 and 95, in NGC 3766. On the right, differential magnitudes for No. 1 in the same format. Representative error bars are shown in the upper right of each plot.

is rich with transient Be stars. In an effort to detect NRPs and study the formation of these transient disks, we are currently performing a long-term photometric study of the cluster. Here we present preliminary differential light curves that reveal magnitude variations of several Be stars that are consistent with NRPs.

2. Observations and Data Analysis

We observed the cluster NGC 3766 using the CTIO 0.9m telescope and SITe 2048 CCD from 2008 March 19–24. The CCD was used in the quad readout mode without binning. We used Strömgren *uvby* filters and exposure times of 120, 20, 10, and 10 s, respectively. No additional standard stars were measured. Sky flats were used to calibrate the u and v filters, and dome flats were used for the b and y filters.

The Strömgren *uvby* photometric data were zero-corrected and flat field-corrected using standard routines in IRAF using the *quadred* package. The *daofind* and *phot* procedures were used to automatically identify the stars and perform aperture photometry. We used the numbering scheme established by Ahmed (1962) and found in the WEBDA database to identify the stars. Differential magnitudes were determined for the variable Be stars identified in Balona & Engelbrecht (1986) and McSwain et al. (2008) and four check stars, Nos. 16, 95, 111, and 147. The check stars have constant differential magnitudes within the measured errors, shown in Figure 1 (left). Figures 1 (right) and 2 show differential light curves for the Be stars Nos. 1, 20, and 63 with variations in magnitude consistent with NRPs.

3. Results and Further Work

Nineteen of the 25 Be stars measured at this preliminary stage have magnitude variations consistent with NRPs with periods on the order of several hours. For example, the u-band light curve of No. 20 was folded using a period of about 6.98 hours, shown in Figure 3.

Additional data collected at the CTIO 0.9m telescope in 2008 June, 2009 February,

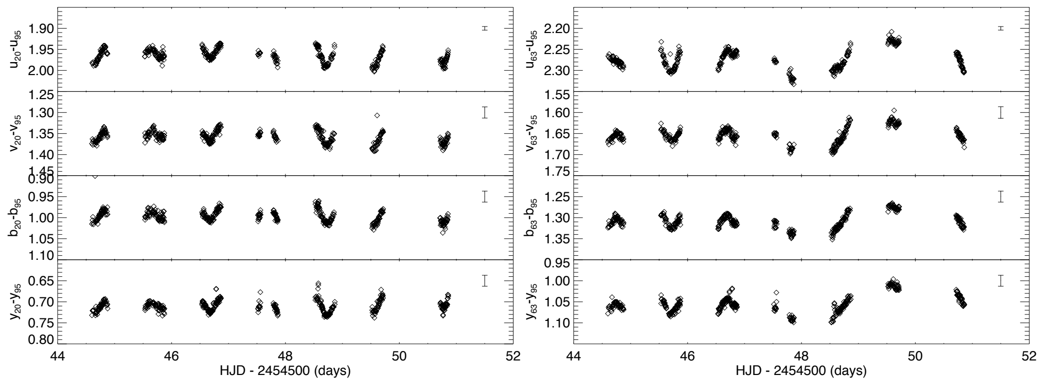

Figure 2. Differential photometry for Nos. 20 and 63 in the same format as Figure 1.

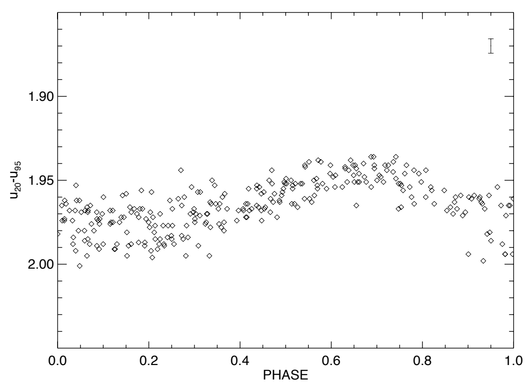

Figure 3. The folded u-band light curve for No. 20 using a period of 6.98 hours.

and 2009 May on NGC 3766 will be analyzed in conjunction with these data to perform a period search and identify the various periods that are present. In the future, we will construct a model for the non-radial pulsations that will allow theoretical light curves to be generated and compared to the observed light curves. Assuming slowly rotating stars, the non-radial pulsations can be modeled by spherical harmonic perturbations of a spherical stellar surface, given by Buta & Smith (1979) as

$$\frac{\delta R}{R} \sim A_\ell^m Y_\ell^m(\theta,\phi) e^{\imath \sigma_\ell^m t},$$

where $\delta R/R$ is the fractional change in radius, A_ℓ^m is the amplitude associated with spherical harmonic $Y_\ell^m(\theta,\phi)$, and σ_ℓ^m is the frequency of the mode. Pole-on and inclined examples of spherical harmonics (with greatly exaggerated amplitudes) are presented in Figure 4. The most commonly observed mode of pulsation in Be stars is $l = |m| = 2$ (Rivinius, Baade, & Štefl 2003), but for illustrative purposes, $l = m = 8$ is presented.

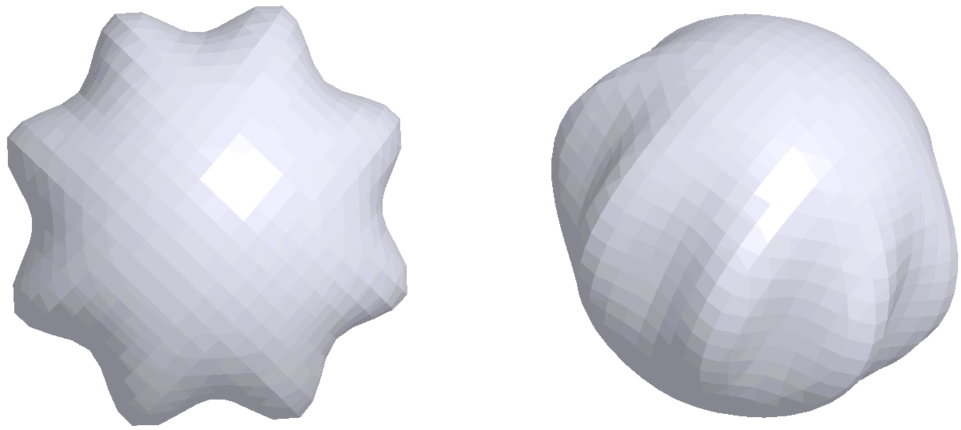

Figure 4. A pole-on and an inclined model of a sphere distorted by non-radial pulsations, with $l = m = 8$. This is a highly exaggerated model of both the amplitude and high order of pulsations for display purposes.

4. Acknowledgements

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